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Optical reflection spectra of open ZnCdSe/ZnSe nanowires

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Most of the nanostructures fabricated by lithography and subsequent chemical etching have in their active zones surfaces directly open to air. Large difference between the dielectric constants of semiconductor and vacuum on vertical side walls in such structures lead to spatial redistribution of the electric components of the electromagnetic field in the vicinity of the structures. In open (unovergrown) quantum well wire (QWW) structures in particular such redistribution result in strong linear optical anisotropy [1]. This linear anisotropy is much stronger than one due to QWW effect itself and it can be observed for wires the width of which in nanoregion is much larger than necessary for quantum wire effect. Further we will use for such structures the term nanowires. Strong linear polarization along wire axes was observed in open QWW luminescence and Raman spectra in [2, 3]. The presented paper is devoted to investigation of the linear anisotropy of the optical reflection spectra in open nanowires (ONW) ZnCdSe/ZnSe.

Open ZnCdSe/ZnSe nanowires were fabricated using interference lithography with subsequent Reactive Ion Etching [4] from undoped structures contained 5 nm thick $Zn_{1-x}Cd_xSe$ single quantum well ($x = 16\%$) sandwiched between 20 nm cap and 25 nm buffer ZnSe layers and grown on GaAs (100) substrate. The period of wire-array structure was equal to $L = 250$ nm. The wires had almost rectangle cross section with width $a = 70$ nm and height $b = 60$ nm.

The investigation of the reflection spectra was carried out for one of the obtained samples with ONW at $T = 77$ K. The measurements were made at normal incident angle of the collimated (0.5°) white light beam with linear polarization parallel or perpendicular to the wire direction. Different laser lines with close excitation density values ($\sim 10\,W/cm^2$) were used for the investigation of the influence of additional photoexcitation on the reflection spectra.

The reflection spectra for the light polarized parallel ($R_\perp(\lambda)$) and perpendicular ($R_\parallel(\lambda)$) to the wire direction are presented in the Fig. 1, which shows the essential difference in the "background" (without exciton peculiarities) reflection values $R_\perp(\lambda)$ and $R_\parallel(\lambda)$. The relation $R_\perp/R_\parallel$ ranges up to 2.5 in the wavelength range 450–500 nm. An increase of the reflection coefficients in high energy region is evidently connected with broad interference minima in spectral region 440–470 nm.

The additional pumping of photocarriers by laser line 441.6 nm lead to increasing of $R_\perp$ values on $\sim 15\%$ in the all measured wavelength range but it does not change the $R_\parallel$ spectrum. Additional photoexcitation ($\lambda_{ex} = 488-632.8$ nm) inside forbidden band gap of the ZnCdSe/ZnSe structure doesn't influence on the reflection spectra.

In the initial quantum well structures additional photocarriers do not have essential influence on the reflection coefficient in wide spectral range exclusive of exciton resonance region. This points to the fact that the $R_\perp$ change is an effect typical for the ONW structures only.

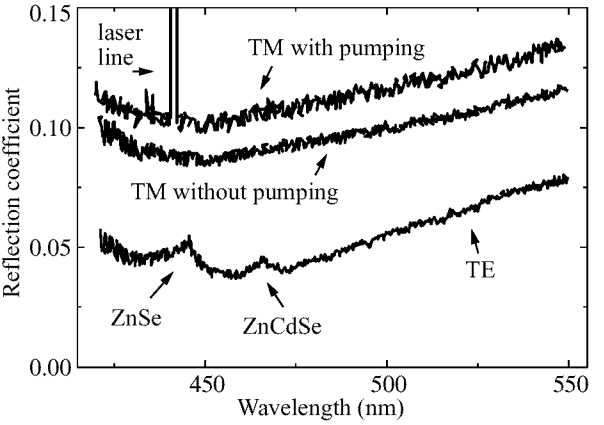

Fig 1.

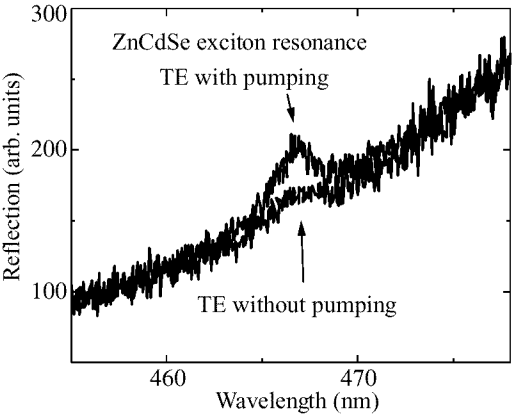

Fig 2.

ZnSe barrier and ZnCdSe layer exciton resonances appear only in the reflection spectra for parallel polarization $R_{\parallel}(\lambda)$. The $R_{\perp}(\lambda)$ spectrum doesn't have any resonance peculiarities. Amplitude of these peculiarities was sensitive to the additional pumping with photon energy more then the ZnSe forbidden gap energy. It is seen from Fig. 2 in which one of the spectra was obtained under simultaneous pumping by the laser line $\lambda_{ex} = 441.6$ nm (luminescence intensity gave neglected small contribution in registered signals). The same changes took place for ZnSe barrier exciton resonance.

The exciton resonance behaviour can be explained taking into account the anisotropy of spatial distribution of the electric component of the electromagnetic field in the vicinity of open nanowires. Local electric fields inside the ONW corresponding to parallel polarization of the external electromagnetic wave (TE-wave) must be essentially larger than corresponding values for perpendicular polarization (TM-wave) [5]. In a dipole approximation the probabilities of optical transition matrix elements are proportional to the scalar product of the local electric field and the interband dipole momentum. As a

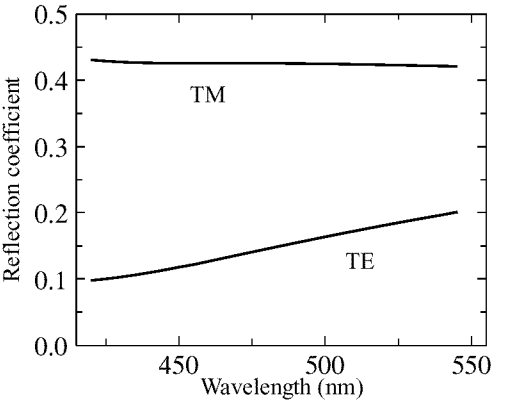

Fig 3.

result due to great difference of the local electric fields the optical transition probabilities for parallel polarization must be larger than the ones for perpendicular polarization. It is the reason of strong linear polarization along wire direction which was observed in luminescence and Raman spectra of open QWW [3]. The manifestation of exciton resonances only in $R_{\|}(\lambda)$ spectra is also connected with the same reason evidently and it shows that the exciton resonance oscillator strength for parallel polarization is much larger than the one for perpendicular polarization.

The influence of additional photocarriers on the exciton resonant amplitudes in the reflection spectra is the result of exciton damping decrease due to the decrease of band bending near nanowires surfaces. Such decrease usually takes place as a result of carrier trapping by charged surface states.

Behaviour of the "background" reflection spectra over the wide spectral range can interpreted in the frame of model, which have been suggested for calculation of short-period grating reflection spectra in [7]. In this case grating corresponding to the surface open ZnSe wire-array structure is considered as an anisotropic uniaxial film on GaAs substrate surface. The film is characterized by two effective refractive indexes n_0 and n_e for the ordinary (TE) and unordinary (TM) waves correspondingly:

$$n_0^2 = a n_{\mathrm{ZnSe}}^2 / L + (L - a) n_{\mathrm{air}}^2 / L,$$

$$1/n_e^2 = a/\left(L n_{\mathrm{ZnSe}}^2\right) + (L - a)/\left(L n_{\mathrm{air}}^2\right).$$

The effective refractive indexes for the film were determined with the use of our real structure parameters including the real and the imaginary parts of ZnSe and GaAs material. At the calculation of the reflection spectra we took into account the reflection from two parallel surfaces (air/film, film/substrate) [8]. The calculated spectra shown in Fig. 3 can qualitatively explain such found feature of the "background" reflection spectra as the essential excess of $R_{\perp}$ over $R_{\|}$. Further theoretical analysis of the reflection spectra is in progress.

Additional photocarries usually lead to the neutralization of the charged states on the wire surface. As a result the built-in transverse electric field distribution are changed essentially. We suggest this changing to be a reason of the pumping influence on the

reflection spectrum $R_{\perp}$ only. It is necessary farther research for the full identification mechanism of this effect.

To conclude, we have found the essential linear polarization anisotropy in the reflection spectra of open nanowires over a wide spectral range. Two mechanisms is responsible for the anisotropy. The first one displayed in exciton resonance region is due to the distribution anisotropy of the electric component of the electromagnetic field in the vicinity of open nanowires. The second one connected with the "background" reflection spectra over the whole spectral range is a consequence of grating effects.

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